DEVELOPMENT OF A PROTOTYPE CONTROLLER FOR A PV POWERED LIGHTING DEVICE

RENEWABLE ENERGY DIVISION

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PREFACE

This Report is the final milestone report on a development contract for an electronic controller to automatically control a Photovoltaic Powered Remote Lighting Device.

The report is intended to summarise the work done under the contract and the results of the performance monitoring on the end product's field trial.

While simple timers can operate lights on and off automatically, the subject device is a much more sophisticated controller that not only allows a nightly lighting profile of a large and a smaller lamp at dusk, it also enables the re-lighting of the lamps towards dawn throughout the entire year. It additionally provides a battery management and charging control function for the PV Power Generating System.

This Report is intended for the Scientific Authority for the contract.

ABSTRACT

This Report summarises the work done under a Development Contract for an electronic controller for a Photovoltaic Powered Lighting Device. The sophisticated controller is designed to adjust the operational times of the lamps to the changing seasons of the year at any given location, with a flexible lighting profile that provides for changing levels of illumination at dusk and dawn along with a continuous lower level of illumination throughout the night.

Additionally the controller regulates the battery charging and provides for a dual level of load disconnect when the battery reaches a reduced state of charge.

This work was an outgrowth of one year of field trials of the prototype light unit itself with a

datalogger control which work defined the alogarithms and the functions required. This was translated into a dedicated micro-processor control unit by Richard M. Fine and Associates into which the variables and program status can be monitored and set by a plug-in hand-held display unit. Allowance is made in the alogarithm for a stored energy inventory with temperature co-efficient corrections.

A sophisticated flexible control device has been developed which can be used in harsh environments for extended management of a Photovoltaic Powered Lighting System.

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SECTION 1.0 INTRODUCTION

A photovoltaic powered highway lighting device has been developed that operates year round in the Canadian climate without any connection to the conventional electrical grid. A prototype unit has been operational since 1985 in Burnaby B.C. and has been monitored for performance by Lenbrook Industries Ltd. and their sub-contractor, United Power Corporation. A detailed description of this device is enclosed as Appendix A. The field test lighting unit at Lenbrook Industries for the prototype controller developed under this contract is a reduced version of the Burnaby unit and is described further in Section 3.0.

This device was developed under an N.R.C. Contract No. OXS 83-00186 and was designed to be a highly reliable free-standing light that will provide all night illumination for twelve months of the year in the Canadian environment. To achieve this performance a variable light profile utilising two luminairies of different sizes was developed that varies with the season of the year. The sophisticated control algorithm provides higher light levels for the hour just at dusk and just before dawn, while a lower light level is maintained throughout the night hours.

A 10 day "no sun" energy reserve is provided in the battery component that is protected against excessive discharge and subsequent damage by a low voltage disconnect incorporated in the controller. In the case of such an emergency disconnect a small neon flasher is activated during operational hours to indicate the outage and also the presence of the device.

To control the light unit, a rather sophisticated algorithm is required to accommodate the changing length of light hours, the temperature compensation for the battery charging regulations, the low voltage disconnect detection and activitation mechanism, the restricted operation of lights in cases of low battery state of charge, and "inventory" maintenance of the stored power.

In the prototype light unit this control was achieved through the use of a Campbell Scientific Ltd. 21X micrologger. This instrument was also used for recording the performance of the prototype by storing the monitored data on a cassette tape. By using this unit the control algorithm was defined and confirmed as practical for operational use on production

lights.

The monitored data indicates the successful operation of the light unit and the provision of adequate design considerations for year round reliability.

In order to make the PV light commercially viable it was perceived necessary to develop a micro-processor control unit to duplicate the control functions of the 21X micrologger unit. The 21X unit is a sophisticated special datalogger that was ideal for the prototype but is too expensive for production units.

This contract was issued to develop the prototype microprocessor control unit for the free-standing light, incorporating the algorithms established previously in the micrologger unit, to build the device in hardware and to field test the unit before commercial production of the controller was initiated.

SECTION 2.0 OBJECTIVES

The objective of the project was to create a flexible cost-effective prototype controller for the PV lighting device utilising two luminaires. The device is intended to function in extremely harsh environmental conditions from extreme cold (-40c) to hot (+50c) conditions. It was intended to perform the management functions for the charging of the storage battery, the operation of the ramped lighting sequence in accordance with the changing seasons, and the protection of the storage unit in the case of excessive discharge demands due to extreme weather.

Due to the nature of the system in that all power will be supplied by the photovoltaic generating component only, it was vital that the power consumption characteristics of the device and the controller device be as low as possible.

In order to minimise the cost of the unit for multiple applications it was decided in the initial planning phase to utilise a hand-held plug-in display interface to the microprocessor as opposed to providing a dedicated display and interface with each microprocessor.

The objective was first to define the operational algorithms for the target microprocessor and then develop a prototype hardware version of the controller. This unit was then bench tested and then installed in a field unit for confirmation of its operational characteristics.

SECTION 3.0 METHODOLOGY

The procedure used in developing the prototype controller was to initially define the specifications of the unit in accordance with the results of the monitoring program of the light prototype. A "Request for Quotation" RFQ was prepared and bids received from several micro electronic design firms in the Toronto area to translate the specifications into a prototype hardware unit for field testing.

Once the successful sub-contractor was selected, meetings were held to review the specifications, operating algorithms, and possible options in the design of the unit. Once the basic parameters were finalised, the contractor then developed an operations manual spelling out in detail the functions of the various codes and functions of the unit. This manual was then submitted for review and approved before the software writing and hardware assembly was commenced.

The prototype controller was then built and bench tested using a test board constructed by the contractor.

A further bench test was performed at Lenbrook facilities before installing in the field unit. Although the original intention was to perform the field test of the controller in the prototype light unit at Burnaby B.C., the field test location was changed to the Lenbrook premises in Pickering, Ontario. This was due to personnel changes at the sub-contractor's operation in Burnaby and the difficulties of distance in resolving problems that might arise in the field test. This was coupled with an installation of PV parking lot lights at the Lenbrook premises, one of which was able to be modified into a similar two light unit which provided a suitable field test bed for the prototype controller.

The field test unit utilized at Lenbrook comprises two luminaires, four modules totalling 176 peak watts, and a 480 AH low antimony lead acid storage battery. A steel pole structure with an inclined module mount was employed to match and blend with the remaining Lenbrook parking lot lights rather than the antenna type tower as used at Burnaby. This is shown in Figure 1.

After the modifications were made on the subject light standard, the unit was installed for field testing. A Campbell Scientific 21X Micrologger Unit was also installed

to record the operational data of the system for processing and analysis.

Unfortunately an intermittent malfunction of the controller necessitated a return of the prototype to the sub-contractor for repair and at the same time some changes were made in the algorithm to better reflect the cold weather effects on the battery storage. Additionally at this time a revised method of measuring the DC currents from the array and the battery was incorporated utilising "hall effect" devices.

Further bench tests were performed after the modifications were completed to confirm the operational characteristics and the controller was returned to the Lenbrook facilities for installation again in the field test unit.

The micro-processor design and build was performed by Richard A. Fine and Associates of Mississauga and the monitoring function and contract management was performed by Adkinson & Associates of Pickering, Ontario. Mr. Eric Kalmbach as Manager of the Energy Division and Mr. Ron Mason, Photovoltaic Specialist, were responsible for design contributions and the bench and field testing of the units at the Lenbrook facility.

SECTION 4.0 RESULTS

In operational terms a prototype controller has been developed which functions extremely well in the control and operation of a remote PV powered lighting device. It is able to regulate the power into the battery and protect the battery storage component from excessive discharge with a two level load control and battery disconnect feature. It is able to provide a daily operational window for the lighting devices that is changed daily and corrected monthly to the local sunrise and sunset times. The operating algorithm of the unit takes into consideration the "end of charge voltage" set point of the battery relative to the battery temperature, as well as the cold temperature effects on the battery charge efficiency and its ability to deliver the stored power.

In physical terms the prototype controller is mounted on a wire wrap board that is somewhat larger than originally anticipated and is enclosed in a NEMA waterproof enclosure that measures 6" x 12" x 16". A final production design would be somewhat condensed and it is expected that this would fit into a 4" x 8" x 10" enclosure.

The hand-held interface unit is a compact 4" x 3" x 8" lightweight unit that is connected to the prototype controller by means of RS232 serial port connector at the end of a 1 metre ribbon connector cable. The hand-held unit comprises a one line digital display of the LCD type and a 12 button key pad plus an internal thermostatically controlled heater to maintain the operating temperature of the LCD display unit.

Photographs of the units are shown in Figures 1, 2 and 3.

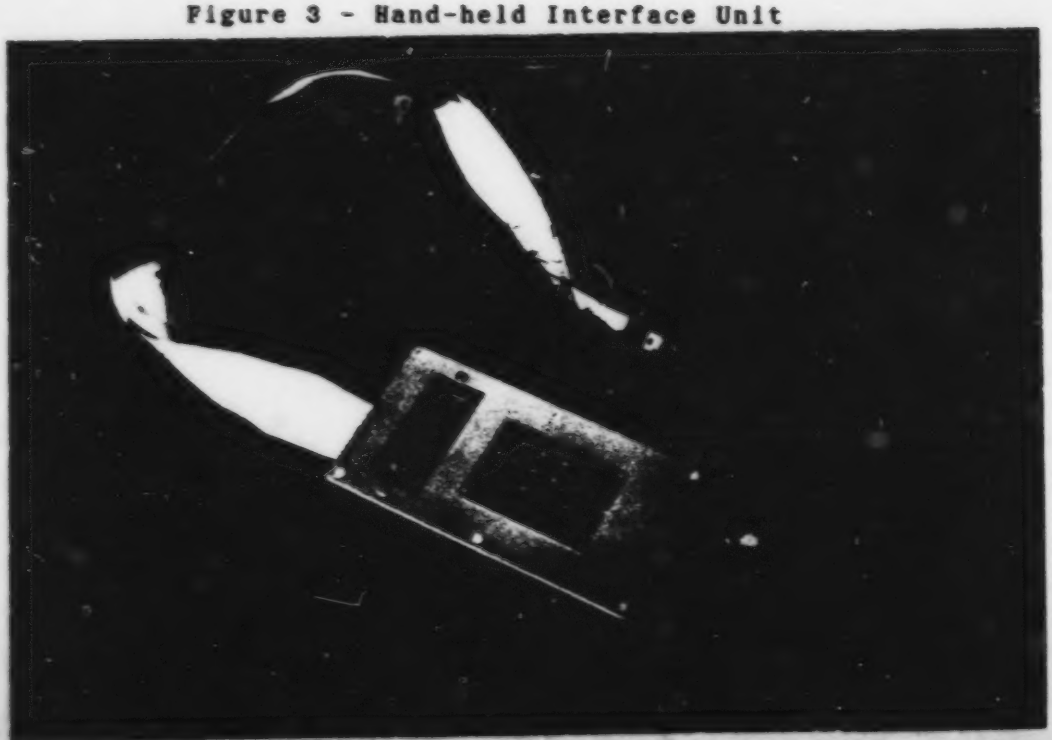
The controller is an extremely flexible device capable of handling two lights plus an emergency flasher, any size battery storage capacity, sunrise and sunset times for any location by entering only six monthly values, and various efficiency factors for different battery types.

As described in the Manual of Operations in Appendix B, there are a total of 30 functions that are accessible by the hand-held interface. The total number of input values that can be varied for specific site operation is 17. All the functions and factors have default values built into the RAM storage of the microprocessor.

Figure 1 - Installed Lighting Device

Figure 2 - Prototype Controller Unit

Figure 3 - Hand-held Interface Unit



Production costs were estimated on a duplication of the prototype unit using the same parts etc. and vary from roughly $600 in quantities of 50 down to $480 in volumes of 500 units. These estimates have been made using identical parts and catalogue prices for the components and it is anticipated that actual production quotations after negotiations with a production house regarding parts replacement etc. would result in a minimum of a one-third reduction in the above quoted costs.

SECTION 5.0 DISCUSSION

The decision to utilise a hand-held plug-in type interface unit was based on reducing the per unit cost of multiple light standard installations as well as the need to maintain a minimum operating temperature for a liquid crystal display of the interface. By enclosing the LCD (Liquid Crystal Display) in the hand-held unit a very small heater could be installed in the unit that would require minimum current and also be disconnected from the operational unit when the operator left. The incremental cost of putting the interface into the hand-held unit was minimal for the single unit purchaser i.e. $20 while offering a significant cost reduction for the multiple unit purchaser i.e. $50-$60.

Unfortunately minimal monitoring results are available at this time due to the intermittent fault in the controller when first installed for the field test. The results obtained to date however indicate operation in accordance with the expectation and it is intended to continue the monitoring of the unit for the immediate future.

In light of the difficulties encountered with the intermittent fault in the control unit it would seem that the decision to perform the field test at the Lenbrook site as opposed to the West Coast site was a wise decision despite the delay in finding the exact location for the lighting standard. The modifications of the battery inventory control algorithm appear to function but this will not be confirmed until an actual cold weather period has been experienced.

While the controller has been designed to perform specifically with a two lamp remote lighting device, the loads controlled could be items other than lamps such as fans or pumps etc. with much larger loads being provided for by simply modifying some of the control component capacities. The operation of the control is tied to the sunrise and sunset times and the periods of activation of the individual loads are completely flexible. While no other specific application has at this point been identified, the capabilities of the unit would make the controller a candidate for a much wider application than just the lighting device application.

SECTION 6.0 CONCLUSIONS AND RECOMMENDATIONS

A flexible and functional photovoltaic system control device has been developed to the prototype stage. It functions well in the field test in the lighting device and would appear to have wider application possibilities.

The device does essentially what was intended in the original design with a great flexibility for optimising the use of various types of lights and batteries.

The field test has not been through an extreme cold weather period and it is recommended that monitoring be continued throughout the next winter to obtain further data on the cold weather operations.

Before actual production begins on the intial run of product further design modifications will be required in conjunction with a manufacturer in order to optimise the value of the end product and to minimise the cost of production. Such items as plug-in versus hard-wired design for the mounting of the printed circuit board as well as the relays and terminal strips etc. are the types of decisions to be made. A number of options are available and will be resolved before the first production is commissioned.

APPENDIX A

Description of Lighting Device

PROTOTYPE DESIGN DESCRIPTION

TITLE: Photovoltaic Powered Lighting System

Contract:OSX83-00186 File No.:01SX.31926-3-3025

1. Application:

The prototype unit is intended for use as a highway lighting device for an intersection or curve in relatively remote areas where a grid connection is not available for AC power.

2. Light Source:

The light source utilized is the low pressure sodium type lamp that is exceptionally efficient in developing in excess of 100 lumens per watt of input power. A dual light source has been employed that utilizes both an 18 watt and a 35 watt lamp to enable an effective variable light profile to be produced. The luminaire fixtures have built into them the necessary power conditioning units to operate directly from a 12 volt DC supply.

An emergency neon flasher light is incorporated into the system that will be activated if the battery has reached a low 20% state of charge and the luminaires have been turned off to protect the battery. This will provide an indication that the system has been disconnected and also still provide a warning to the motorist who is accustomed to the light being there.

3. Load Management:

As the necessity is evident to optimize the use of the limited amounts of electrical power that can be produced and stored with practical size components, a "smart "controller is required to achieve this optimization. A commercial unit that can also be effectively employed in monitoring the performance of the prototype system has been used in the prototype with the intention of later developing a customized microprocessor device for use in production models. The 21X MIcrologger device supplied by Campbell Scientific Ltd. has been selected for this purpose.

This unit has the capability of expanding the night time hours in accordance with the season to allow the load profile to operate year round. In addition, the "smart" controller will assess the state of charge of the battery and allow only the smaller of the two lights to

come on if the power stored is below predetermined limits. It would also ultimately be capable of recognizing a weather trend i.e. if it is sunny today the odds are that it will be sunny tomorrow as well, and thus risk a lower state of charge by full operation during the night rather than if the weather had been cloudy and no solar input were detected during the preceeding daylight hours.

The load reduction or restriction to one lamp only will occur when the SOC of the battery drops to approximately 35% or less and the lamp load will be disconnected completely in order to protect the battery and the emergency flasher will be activated instead at an SOC of 20%. In the prototype controller the SOC will effectively be assessed by the measuring of the battery terminal voltage adjusted for temperature, but additionally an inventory of power into the battery (derated by 15 % for battery inefficiency) (chemical to electrical conversion) and power out to the load will be maintained for a separate SOC (state of charge) determination. These two SOC calculations will be analyzed and compared during the monitoring phase.

4. Load Profile:

The load profile established for the prototype system is one that utilizes the two lamp design allowing both units to ignite at dusk. Photosensors connect the lights when the need for illumination is the greatest both from the optical and from the traffic demand points of view. As the night darkens the illumination level is lowered by extinguishing one lamp so that only the larger lamp operates for a predetermined period of approximately 30 minutes. The smaller of the two lights is then lit again, the larger turned off and then only the smaller one operates for the bulk of the night time hours. As dawn approaches and the need for a higher level of illumination develops, the other lamp is again ignited , the ramp profile is repeated in reverse so that both lamps are shedding light together until dawn and both are shut down. These ramp periods are readily adjustable by software in the control unit.

If the battery state of charge (SOC) is less than 35%, only one lamp will operate and if the SOC drops to 20% , no regular lamp will operate and a low powered flashing neon light only will be activated during the normal lighting hours. During daylite hours when the operating window is closed , the flasher also will be extinguished. The voltage levels to determine the SOC are also flexible and easily reset in the control unit.

5. Array of PV Modules:

The minimum size array required is ten modules of the SX 120 style each with 40 peak watts of electrical output. The face area of this array is approximately 55 sq. feet and the angle of inclination is 90' to optimize the solar input during the low irradiation months of winter. They are mounted vertically on the one face of the triangular tower structure with a ground clearance height of seven feet to avoid vandalism. While a slight loss of 5% is predicted for the output during December because of the 90' versus the optimum 70' mounting, a more attractive appearance and economical construction resulted.

The array is designed to produce sufficient power during December, (worst month condition) to support the load completely for the whole month.

6. Batteries:

The battery storage component will accommodate ten days power storage for a potential period of ten days without solar input to the system. This figure has been confirmed by means of computer simulation in the final design task. The battery life anticipated is a minimum of five years with a good expectation of ten years.

The batteries are two volt stationary type lead acid cells configured in series for operation as a twelve volt system. The charge voltage to the units is controlled by a charge regulator which is temperature compensated to ensure proper charging voltage and to avoid under or overcharging voltages where possible.

7. Structure:

The support structure for the prototype unit is an open web type three legged tower approximately forty five feet tall. While solid pole type structures of concrete or wood are optional mounting structures, the three legged tower will facilitate changing mounts, wiring, orientation etc. during the testing phase. The initial tower utilized is lighter than the design requires for a free standing structure and will require guying which is readily done in the prototype location. The delivery time restraints dictated the use of this model for the prototype.